TITLE: WIRELESS TERMINAL OPERATIONS WITHIN WIRELESS LOCAL AREA
         NETWORK

SPECIFICATION

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. Provisional Patent Application Serial No. 60/398,744, filed July 26, 2002 and to U.S. Regular Utility Patent Application Serial No. 10/357,795, filed February 4, 2003, both of which are incorporated herein by reference in their entirety for all purposes.

1.   FIELD OF THE INVENTION

This invention relates generally to wireless local area networks; and more particularly to the management of service coverage areas within such wireless local area networks.

2.   BACKGROUND OF THE INVENTION

Communication technologies that link electronic devices in a networked fashion are well known. Examples of communication networks include wired packet data networks, wireless packet data networks, wired telephone networks, wireless telephone networks, and satellite communication networks, among other networks. These communication networks typically include a network infrastructure that services a plurality of client devices. The Public Switched Telephone Network (PSTN) is probably the best-known communication network that has been in existence for many years. The Internet is another well-known example of a communication network that has also been in existence for a number of years. These communication networks enable client devices to communicate with each other on a global basis. Wired Local Area Networks (LANs), e.g., Ethernets, are also quite common and support communications between networked computers and other devices within a serviced area. LANs also often link serviced

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devices to Wide Area Networks and the Internet. Each of these networks is generally considered a "wired" network, even though some of these networks, e.g., the PSTN, may include some transmission paths that are serviced by wireless links.

Wireless networks have been in existence for a relatively shorter period. Cellular

5   telephone networks, wireless LANs (WLANs), and satellite communication networks, among others, are examples of wireless networks. Relatively common forms of WLANs are IEEE 802.11(a) networks, IEEE 802.11(b) networks, and IEEE 802.11(g) networks, referred to jointly as "IEEE 802.11 networks." In a typical IEEE 802.11 network, a wired backbone network couples to a plurality of Wireless Access Points (WAPs), each of which supports wireless

10   communications with computers and other wireless terminals that include compatible wireless interfaces within a serviced area. The wired backbone network couples the WAPs of the IEEE 802.11 network to other networks, both wired and wireless, and allows serviced wireless terminals to communicate with devices external to the IEEE 802.11 network.

WLANs provide significant advantages when servicing portable devices such as portable

15   computers, portable data terminals, and other devices that are not typically stationary and able to access a wired LAN connection. However, WLANs provide relatively low data rate service as compared to wired LANs, e.g., IEEE 802.3 networks. Currently deployed wired networks provide up to one Gigabit/second bandwidth and relatively soon, wired networks will provide up to 10 Gigabit/second bandwidths. However, because of their advantages in servicing portable

20   devices, WLANs are often deployed so that they support wireless communications in a service area that overlays with the service area of a wired network. In such installations, devices that are primarily stationary, e.g., desktop computers, couple to the wired LAN while devices that are

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primarily mobile, e.g., laptop computers, couple to the WLAN. The laptop computer, however, may also have a wired LAN connection that it uses when docked to obtain relatively higher bandwidth service.

When a decision is initially made to install a WLAN in a premises, the WLAN must first be engineered. In such engineering, the lay out of the premises, e.g., warehouse, office space, campus environment, etc. is first considered. In most installations, wireless coverage is desired across all areas of the premises. The deployment of the WAPs within the premises is the most critical step in the WLAN engineering. Because the conductance of Radio Frequency (RF) transmissions through building walls and other obstacles in the premises is dependent upon respective structure, the structural aspects of the premises must be carefully considered when determining WAP placement. However, most WAP placement decisions are subjectively made, based upon the care and experience level of the installer.

During the initial WLAN installation, the WAP placement is fixed. Thus, the WAP placement cannot address changes in the topology and structure of the premises. Such changes in the topology and structure may include the addition of walls, the additions of partitions, the addition of wiring that will affect propagation of RF transmissions, and other characteristics. Problems that typically result due to poor WAP placement include poor channel utilization, interference between WAPs, WAP capacity shortages, and other shortcomings. These operational problems, however, will typically only be seen as poor WLAN performance. The WLAN network installer/administrator, however, has no way of determining whether these problems are caused by equipment deficiencies, the nature of the premises, WAP placement, or lack of capacity in the WAPs.

Further problems relate to the manner in which wireless terminals access WAPs within the WLAN. Wireless terminals generally listen for a beacon from a WAP and, upon receipt of a first beacon, request attachment to the corresponding WAP. While this process is simple and results in minimal complexity it tends to overload some WAPs while not loading other WAPs,

5   leading to poor WLAN performance.

Thus, there is a need in the art for improvements in the management of WAPs servicing a WLAN.

SUMMARY OF THE INVENTION

Thus to overcome the shortcomings of the prior devices among other shortcomings, a

10   wireless terminal operates within a Wireless Local Area Network (WLAN) and includes a directional antenna, a radio frequency unit operably coupled to the directional antenna, and a processor operably coupled to the radio frequency unit. The processor controls the operation of the wireless terminal to operate within the WLAN to assist in WLAN service management. In its operations, the wireless terminal listens to a plurality of beacons transmitted by a corresponding

15   plurality of Wireless Access Points (WAPs) of the WLAN. The wireless terminal then characterizes the plurality of beacons with regard to signal quality. Based upon the characterization, the wireless terminal selects a desired WAP of the plurality of WAPs. The wireless terminal then associates with the desired WAP of the plurality of WAPs. Finally, the wireless terminal adjusts a gain vector of a servicing antenna of the wireless terminal so that it is

20   substantially directed toward the desired WAP of the plurality of WAPs.

In its additional operations, the wireless terminal may again listen to the plurality of beacons and again characterize the plurality of beacons with regard to signal quality. Based upon

this characterization, the wireless terminal may select a different WAP of the plurality of WAPs, disassociate with the desired WAP of the plurality of WAPs, and associate with the different WAP of the plurality of WAPs. The wireless terminal may then adjust the gain vector of the servicing antenna of the wireless terminal so that it is substantially directed toward the different

5   WAP of the plurality of WAPs.

When the wireless terminal listens to the plurality of beacons, it may sweep the gain vector of the servicing antenna until a beacon is detected. When the beacon is detected the wireless terminal may then characterize the beacon. In this operation, the beacon is characterized when the gain vector of the servicing antenna is substantially directed toward the beacon.

10   Characterization of the beacon may take one or more of a number of characterization operations. In a first operation, characterizing the plurality of beacons with regard to signal quality includes measuring signal strengths of at least some of the plurality of beacons. In a second operation, characterizing the plurality of beacons with regard to signal quality includes measuring a signal to noise ratio corresponding to at least some of the plurality of beacons. In a third operation,

15   characterizing the plurality of beacons with regard to signal quality includes receiving loading data carried by at least some of the plurality of beacons and processing received loading data to determine the desired WAP of the plurality of WAPs. Loading data represents the amount of traffic serviced by a WAP as reported in its beacon. It may be the case that a wireless terminal may select a WAP based upon not only the signal quality that is provided by the WAP but upon

20   the service level that the WAP may provide to the wireless terminal.

In a fourth operation, characterizing the plurality of beacons with regard to signal quality includes receiving capability data carried by at least some of the plurality of beacons, wherein the

capability data indicates whether a corresponding access point is capable of directional antenna servicing and processing received capability data to determine the desired WAP of the plurality of WAPs. In a fifth operation, characterizing the plurality of beacons with regard to signal quality includes receiving capability data carried by at least some of the plurality of beacons,

5   wherein the capability data indicates whether a corresponding access point is capable of transmit power control and processing received capability data to determine the desired WAP of the plurality of WAPs.

In one of its constructs, the directional antenna of the wireless terminal includes a single antenna having a plurality of antenna elements and a directional antenna controller operably

10   coupled to the single antenna and to the radio frequency unit. In another of its constructs, the directional antenna of the wireless terminal includes a plurality of antennas and a directional antenna controller operably coupled to the plurality of antennas and to the radio frequency unit.

Other features and advantages of the present invention will become apparent from the following detailed description of the invention made with reference to the accompanying

15   drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will be more fully understood when considered with respect to the following detailed description, appended

20   claims and accompanying drawings wherein:

FIG. 1 is a system diagram illustrating a premises in which a Wireless Local Area Network (WLAN) constructed according to the present invention is deployed;

FIG. 2 is a partial system diagram illustrating a portion of the campus of FIG. 1 in which wireless communications are serviced according to the present invention;

FIG. 3 is a partial system diagram illustrating a portion of a campus in which wireless communications are serviced according to the present invention;

FIG. 4 is a partial system diagram illustrating a WLAN constructed according to the present invention;

FIG. 5 is a partial system diagram illustrating in more detail the WLAN of FIG. 4;

FIG. 6A and 6B are graphs illustrating various antenna gain patterns of WAP directional antennas operating according to the present invention;

FIG. 7A is a block diagram illustrating a WAP constructed according to the present invention;

FIG. 7B is a block diagram illustrating the components of a wireless terminal that operates according to the present invention;

FIG. 8 is a block diagram illustrating an air controller constructed according to the present invention;

FIGs. 9A and 9B are a logic diagrams illustrating WAP operations according to the present invention;

FIG. 10 is a logic diagram illustrating air controller operations according to the present invention; and

FIG. 11 is a logic diagram illustrating mobile terminal operations according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. 1 is a system diagram illustrating a premises 100 in which a Wireless Local Area Network (WLAN) constructed according to the present invention is deployed. The premises 100 (campus) includes office buildings 102, 104, 106 and industrial buildings 108, 110, 112, and 114.

5   The premises 100 may correspond to a company such as a technology company, a seller of goods, a service company, or another type of company. Contained within each of the office buildings 102, 104, and 106 are a number of offices, each of which provides a working space for at least one person. Each of the industrial buildings 108, 110, 112, and 114 provides space for manufacturing, storage, and/or another purpose. People also work within industrial buildings

10   108, 110, 112, and 114.

Contained within each of these buildings 102-114 are computer workstations, computer servers, printers, FAX machines, phones, and other electronic devices. Each of these electronic devices has its communication requirements. For example, computer workstations, computer servers, and printers each require data communication service. Such data communication service

15   requires that the devices can communicate with other devices located within the premises 100 and with devices located external to the premises 100 across one or more data networks. The FAX machines and phones require coupling to one another and to the Public Switched Telephone Network (PSTN).

FIG. 2 is a partial system diagram illustrating a portion of the campus of FIG. 1 in which

20   wireless communications are serviced according to the present invention. A building floor 200 shown in FIG. 2 may be a lower floor of one of the buildings of FIG. 1, e.g., building 102. The building floor 200 includes a plurality of rooms 202, 204, 206, and 208. Each of these rooms

202, 204, 206, and 208 has placed therein WAPs 206A, 206B, 206C, 206D, and 206E, respectively, that service corresponding areas. Further, an external WAP 206F services an area external to room 208 of building floor 200. Each of these WAPs 206A-206F couples to a wired network infrastructure that may include a building router 216.

5   Serviced within the building floor 200 are wireless telephones/data terminals 212A-212I and laptop computers 214A-214H, together "wireless terminals." Each of these wireless terminals wirelessly communicates with a servicing WAP. For example, laptop computer 214A and wireless terminals 212A and 212B wirelessly communicate with WAP 206A (in their illustrated positions). Each of the WAPs 206A-206E supports wireless communications

10   primarily within a designated area respectively. However, the coverage area of each WAP 206A-206E extends beyond the boundaries of the serviced rooms 202-208 so that overlapping coverage areas exist. For example, WAPs 206A and 206C provide service between rooms 202 and 206 so that wireless terminals that roam between the rooms continue to receive wireless communication service when between the rooms 202 and 206. Further, WAP 206E supports wireless

15   communications outside of the floor 200 to service laptop computer 214H and wireless terminal 212I.

FIG. 3 is a block diagram partially illustrating a portion of the WLAN of FIG. 2 that supports operations according to the present invention. The portion of the network shown includes WAPs 206A and 206B that support wireless communications within a serviced area, for

20   example, the rooms 202 and 204 of FIG. 2. The WAPs 206A and 206B couple to a wired backbone network 305. The WAPs 206A and 206B service wireless communications for laptop computers 306, 308, and 310, desktop computers 312, 314, 316, and 318, and wireless

telephones/data terminals 320, 322, 322, 324, 326, and 328, together "wireless terminals." Note that while different numbering is used for the wireless terminals of FIG. 3, they are the same as, or similar to wireless terminals of FIG. 2. Service coverage areas supported by WAPs 206A and 206B partially overlap. The wired backbone network 305 couples to one or more data networks and to an air controller 326.

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As illustrated, each of the WAPs 206A and 206B includes two antennas. A first antenna of the two antennas is a dynamically directional antenna that couples to a first radio of a respective WAP and a second antenna of the two antennas couples to a second radio of a respective WAP. The directional antennas and first radios of the WAPs 206A and 206B service wireless communications with those of the laptop computers 306, 308, and 310, desktop computers 312, 314, 316, and 318, and wireless telephones/data terminals 320, 322, 322, 324, 326, and 328, together "wireless terminals," operating within respective service areas. As will be described further with reference to FIGs. 4-10, the WAPs 206A and 206B are controlled by the air controller 326 so that their respective service areas do not unduly interfere with one another and such that satisfactory service is provided therein. In such case, each of WAPs 206A and 206B provides service to a subset of the wireless terminals.

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In controlling the WAPs 206A and 206B, the air controller 326 directs the WAPs 206A and 206B to alter the gain pattern of their directional antennas, to modify their first radio transmit powers, and to alter the channels upon which they operate, among other directions. The control of the WAPs 206A and 206B by the air controller 326 is based upon WAP operational reports received from the WAPs. Second radios of the WAPs 206A and 206B listen to transmissions from at least one of the wireless terminals and WAPs and collect non-participatory WAP data.

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The WAPs 206A and 206B produce the WAP operational reports based upon the non-participatory WAP data and forward the WAP operational reports to the air controller 326. In some operations, the WAP operational reports may also include information gathered by the WAPs 206A and 206B based upon the communications serviced by the first radio -- participatory

5   WAP data. Participatory WAP data may include received carrier signal strengths, carrier to interference ratios, bit error rates, dropped link occurrences, and channel utilization. Non-participatory WAP data may include received carrier signal strengths, carrier to interference ratios, and channel utilizations. Based upon the WAP operational reports, the air controller 326 controls the service areas of the plurality of WAPs 206A and 206B. Resultantly, the air

10   controller 326 reduces Radio Frequency (RF) interference among the plurality of WAPs, ensures that coverage is provided within all desired areas of the premises, and provides specialized service when required, e.g., VoIP service.

According to another aspect of the present invention, that will be described further with reference to 7B and 7C, the WAPs 206A and 206B also control the directionality (and transmit

15   power) of serviced wireless terminals. In performing this function, the WAPs 206A and 206B listen to the strength of the received transmissions from a managed wireless terminal, determine a gain vector for a directional antenna of the wireless terminal and have the wireless terminal control its directional antenna to meet this gain vector. Generally, the gain vector will correspond to the location of a servicing WAP, WAP 206A for example. By directing the gain

20   of the directional antenna of the wireless terminal toward the servicing WAP 206A, interference with non-servicing WAPs is reduced and the ability of the servicing WAP 206A to service the wireless terminal is improved. Still other aspects of the present invention will be described with

reference to FIG. 11 that detail how wireless terminals may be operated within a WLAN.

FIG. 4 is a partial system diagram illustrating a WLAN constructed according to the present invention. As shown in FIG. 4, the WAPs 206A, 206B, 206C, and 206D are located across the serviced premises. Each of the WAPs 206A through 206D and the air controller 326

5   couples to the wired backbone network 305 (not in FIG. 4). As is further illustrated, each of the WAPs 206A through 206D includes a directional antenna 404A through 404D, respectively, and a second antenna, 402A through 402D, respectively.

WAP 206A services communications with a laptop computer 306 using its first radio and its directional antenna 404A. However, according to the present invention, each of the WAPs

10   206A, 206B, 206C, and 206D also listens to transmissions from the laptop computer 306 (and also to transmissions from the WAP 206A in some embodiments). In these operations, the WAPs 206A through 206D use antennas 402A through 402D and second radios, respectfully, to listen to transmissions of the laptop computer 306.

As will be further described herein with reference to FIGs. 5 through 10, in listening to

15   transmissions of the laptop computer 306 and each other transmitting wireless terminal within the service premises and other sources of interference, the WAPs generate WAP operational reports. These WAP operational reports are forwarded by the WAPs 206A through 206D to the air controller 326. Based upon the WAP operational reports the air controller produces directions which are sent to one or more of the WAPs 206A through 206D. Then, based upon its

20   directions, the WAPs 206A through 206D alter the operations of their directional antennas 404A-404D, respectively, alter the transmission power of their first radios, and/or alter the channels of operation of the first radios. According to another aspect of the present invention, when the

WAPs 206A-206D include only a single radio and a single antenna, the WAPs 206A-260D listen to transmissions of non-serviced wireless terminals when they are idle with respect to their serviced wired terminals. Thus, with the embodiment, the WAPs 206A-206D are able to collect non-participatory WAP data and participatory WAP data using a single radio.

5   As will be further described with reference to FIGs. 7B and 11, the wireless terminal 306 may include a directional antenna that is employed to direct the gain pattern of the antenna toward a servicing WAP. The servicing WAP is selected from the available WAPs 206A-206D based upon the service characteristics of the WAP. The service characteristics may take a number of forms and are described further herein with reference to FIG. 11.

10   FIG. 5 is a system diagram illustrating in more detail the WLAN of FIG. 4 that operates according to the present invention. FIG. 5 also illustrates the manner in which WAPs 206A through 206D service wireless terminals operating within the premises. As shown, WAP 206A provides RF coverage within a respective service area 502 for wireless terminals 212A, 212B, and 306. Likewise, WAP 206B provides RF coverage within a respective service area 504 for

15   wireless terminals 212C, 212D, 214B and 214C. WAP 206C provides RF coverage within a respective service area 506 for wireless terminals 214D, 214E, and 212F. Finally, WAP 206D provides RF coverage within a respective service area 508 for wireless terminals 212H, 214F, and 214G.

As is illustrated, each of the service areas 502, 504, 506, and 508 has an irregular shape.

20   While these irregular shapes are exaggerated for the illustrative purposes of FIG. 5, each of the WAPs 206A through 206D includes directional antennas 404A through 404D, respectively, that are capable of supporting respective service areas having irregular (and unique) shapes. As was

previously discussed herein, the directional antennas 404A through 404D, the transmit power provided thereto by the coupled first radios, and the channel usage of the first radios are altered via direction from the air controller. As part of this alteration process, varying the directionality of the directional antennas 404A through 404D as well as the transmit power applied to the

5   directional antennas 404A through 404D will alter the service coverage areas 502, 504, 506, and 508 respectively. Such alteration in the service coverage areas 502 through 508 results in reduced interference among the WAPs 206A through 206D. In some operations, WAPs 206A through 206D have differing wireless terminal density within their service coverage areas 502-508. By altering these service coverage areas, the air controller equalizes load among the WAPs

10   206A through 206D. Further, by altering channel usage, varying the directionality of the directional antennas 404A through 404D, as well as the transmit power applied to the directional antennas 404A through 404D that are supported by the WAPs 206A through 206D, the air controller ensures that specialized service requirements, e.g. Quality of Service, VOIP service, are met.

15   FIG. 6A and 6B are graphs illustrating various antenna gain patterns of WAP directional antennas operating according to the present invention. As illustrated in FIG. 6A, a first antenna gain pattern 602 differs from a second antenna gain pattern 604. However, neither gain pattern of 602 or 604 is symmetrical about the antenna. The antenna gain patterns 602 and 604 may be those provided by the directional antennas 404A through 404D of one of the WAPs 206A

20   through 206D.

As shown in FIG. 6B, a first antenna gain pattern 652 is substantially symmetrical. Such would be the case with a monopole or dipole antenna such as the antennas 402A through 402D

of the WAPs 206A through 206B that couple to respective second radios. The second antenna

gain pattern shown 654 may be a gain pattern that is produced by directional antenna 404A

through 404D of the WAPs 206A through 206D.

FIG. 7A is a block diagram illustrating a WAP 206A, 206B, 206C, or 206D constructed

5   according to the present invention. The WAP 206A includes a processor 704 and one or more

storage devices that may include dynamic RAM 706, static RAM 708, EPROM 710, and/or

storage device 712, such as a hard drive, optical drive, tape drive, etc. These components

intercouple via a local bus 717 and couple to a peripheral bus 720 via an interface 718. The

processor 704 may be any type of processing device capable of executing software instructions.

10   The processor 704 may be a single integrated circuit or a processing module including a plurality

of integrated circuits.

The WAP 206A also includes a network interface 724, which couples the WAP 206A to

the wired backbone network 305. The WAP 206A also includes a first radio 726, a second radio

732, directional antenna 742, and antenna 744. The first radio 726 includes a first baseband

15   processor 728 and a first RF unit 730 that couples to the directional antenna 742. The second

radio 732 includes a second baseband processor 734 and a second RF unit 736 that couples to

antenna 744. The embodiment of the WAP 206A illustrated supports at least one standardized

operating protocol, e.g., IEEE 802.11(a), IEEE 802.11(b), IEEE 802.11(g), etc.

In performing operations according to the present invention, the WAP 206A may execute

20   software instructions, i.e., WAP Management Instructions (WMI). WMI 714 enable the WAP

206A to perform the operations of the present invention. In executing the WMI, the WMI 716

are loaded into the storage unit 712 and some or all of the WMI 714 are loaded into the processor

704 for execution. During this process, some of the WMI 716 may be loaded into the DRAM 706. In other embodiments, however, the WAP 206A may operate according to the present invention based upon hardware function, firmware instructions, or a combination of any/all of these.

5   FIG. 7B is a block diagram illustrating the components of a wireless terminal that operates according to the present invention. The wireless terminal 750 includes a directional antenna, a RF unit 754, a processor 756, and a memory 758. The directional antenna includes directional antenna controller 764 and includes at least one antenna element 752 and/or 753. The RF unit 754 couples to the directional antenna, which may be located internal or external to the

10   case of the wireless terminal 750 (external antennas are shown in FIG. 7B). In the described embodiment, the processor 756 controls the directionality of the directional antenna via the directional antenna controller 764.

The processor 756 may be an Application Specific Integrated Circuit (ASIC) or another type of processor that is capable of operating the wireless terminal 750 according to the present

15   invention. The memory 758 includes both static and dynamic components, e.g., DRAM, SRAM, ROM, EEPROM, etc. In some embodiments, the memory 758 may be partially or fully contained upon an ASIC that also includes the processor 756. A user interface 760 includes a display, indicators, a keyboard, a speaker, a microphone, and/or a data interface, and may include other user interface components. The directional antenna controller 764, the radio 754, the

20   processor 756, the memory 758, and the user interface 760 couple via one or more communication buses/links. A battery 762 also couples to and powers the radio 754, the processor 756, the memory 758, and the user interface 760. The structure of the wireless

terminal 750 illustrated is only an example of one wireless terminal structure. Many other varied

wireless terminal structures could be operated according to the teachings of the present invention.

According to one aspect of the present invention that will be described further with

reference to FIG. 11, the wireless terminal 750 controls the directionality of its directional

antenna in operating within the WLAN. In such case, the servicing WAPs may or may not have

directional antennas. According to another aspect of the present invention, the WAPs 206A and

206B assist in the control of the directionality (and transmit power) of the serviced wireless

terminal 750. In performing this function, the WAPs 206A and 206B determine the strength of

the transmissions received from the managed wireless terminal 750, determine a gain vector for a

directional antenna of the wireless terminal 750 and have the wireless terminal 750 control its

directional antenna to meet this gain vector. Generally, the gain vector will correspond to the

location of a servicing WAP, WAP 206A for example. By directing the gain of the directional

antenna of the wireless terminal 750 toward the servicing WAP 206A, interference with non-

servicing WAPs is reduced and the ability of the servicing WAP 206A to service the wireless

terminal is improved. The wireless terminal 750 of FIG. 7B supports these operations.

In performing the operations of the present invention, the wireless terminal 750 may

execute software instructions, i.e., WAP Management Instructions (WMI) 764. WMI 764 enable

the wireless terminal 750 to perform the operations of the present invention. In executing the

WMI, the WMI 764 are loaded from memory 758 into the processor 756 for execution. In other

embodiments, however, the wireless terminal 750 may operate according to the present invention

based upon hardware function, firmware instructions, or a combination of any/all of these.

FIG. 8 is a block diagram illustrating an air controller 326 constructed according to the

present invention. The air controller 326 may be general-purpose computer that has been programmed and/or otherwise modified to perform the particular operations described herein. The air controller 326 includes a processor 802, memory 804, a network manager interface 806, storage 808 and a peripheral interface 814, all of which couple via a processor bus 813. The processor 802 may be a microprocessor or another type of processor that executes software instructions to accomplish programmed functions. The memory 804 may include DRAM, SRAM, ROM, PROM, EPROM, EEPROM, or another type of memory in which digital information may be stored. The storage 808 may be magnetic disk storage, magnetic tape storage, optical storage, or any other type of device, which is capable of storing digital instructions and data.

The network manager interface 806 couples to a network manager console 816, which allows a network manager to interface with the air controller 326. The network manager console 816 may be a keypad/display or may be a more complex device, such as a personal computer, which allows the manager to interface with the air controller 326. However, the network manager may interface with the air controller 326 using other techniques as well, e.g., via a card coupled to the peripheral interface 810.

The peripheral interface 810 couples to a wired network interface 818 and to wireless network infrastructure interface 822. The wired network interface 818 couples the air controller 326 to at least one network 826 that may include a Local Area Network (LAN), a Wide Area Network (WAN), or the Internet. The wireless network infrastructure interface 822 couples the air controller 326 to the wired backbone network 305.

WAP Management Instructions (WMI) 812 are loaded into the storage 808 of the air

controller 326. Upon their execution, a portion of the WMI 812 is downloaded into memory 804

(as WMI 810). The processor 802 then executes the WMI 810 to perform the operations

described herein performed by the air controller 326. The programming and operation of digital

computers is generally known to perform such steps. Thus, the manner in which the processor

5   802 and the other components of the air controller 326 function to perform these operations is not

further described herein.

FIGs. 9A and 9B are a logic diagrams illustrating WAP operations according to the

present invention. Referring particularly to FIG. 9A, operation of the WAP remains idle state

until action according to the present invention commences (step 902). From step 902, the WAP

10   may receive a service request from a wireless terminal (step 904), may employ its second radio to

monitor wireless terminal transmission (step 912), may receive directions from an air controller

(step 920), may receive a system evaluation direction from the air controller (step 930), or may

receive a system beacon direction from the air controller (step 940).

The WAP may receive a service request from any wireless terminal operating in the

15   WAP's service area (step 904). From step 904, the WAP allocates first radio resources for

servicing the wireless terminal (step 906). The manner in which a wireless terminal requests

service from the WAP and the manner in which the WAP responds may be defined according to

a standardized operating protocol, e.g. IEEE 802.11 (a), IEEE 802.11(b), or IEEE 802.11(g).

After first radio resources are allocated, the WAP services the wireless terminal using its first

20   radio (step 908). In servicing the wireless terminal, the WAP may optionally receive

participatory WAP data from the first radio 910. Once the communication has been fully

serviced, operation returns from 910 to step 902.

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From step 912 in which the second radio monitors wireless terminal and/or WAP transmissions, the processor of the WAP receives and stores the non-participatory WAP data (step 914). As has been previously described, the second radio of the WAP is listens to wireless terminal and/or WAP transmissions within the WLAN. In this fashion, the second radio is able

5   to determine when a conflict or sub optimal operating condition exists. In performing this type of listening, the second radio gathers non-participatory WAP data. Optionally, the first radio gathers participatory WAP data that relates to its serviced communications.

In another embodiment of the present invention, each WAP only includes a single radio. In this embodiment, the single radio collects participatory WAP data when it is actively servicing

10   a wireless terminal and collects non-participatory WAP data when it is not actively servicing a wireless terminal but is instead merely listening. In either embodiment, the first radio and/or the second radio provide the non-participatory data (and optionally the participatory WAP data) to the processor.

After receipt of the non-participatory WAP data and optionally the participatory WAP

15   data, the WAP creates a WAP operational report (step 916). In particular, the processor of the WAP creates the WAP operational report. The processor then sends the WAP operational report to the air controller (step 918). The WAP may send the WAP operational report to the air controller periodically or immediately after its creation, or upon request by the air controller. As is evidenced, the WAP operational report may not be created on a periodic fashion because of

20   variations in loading on the WLAN. During high usage times, e.g., during the day, more participatory WAP data and non-participatory WAP data is collected than during low usage times, e.g., night time hours. Thus, the WAP operational reports may be sent from the WAP to

the air controller as is required considering particular system loading conditions.

When the processor of the WAP receives directions from the air controller (at step 920), the processor performs at least one of three different operations. In a first one of these operations, the processor alters the gain pattern of the directional antenna of the corresponding WAP (step 922). In a second operation, the processor alters the transmit power of the first radio of the WAP (step 924). In a third operation, the processor alters the channel allocation of the first radio (step 926). From each of step 918 and 926, operation returns to step 902.

Referring now to FIG. 9B, operations regarding WLAN system evaluation are discussed. Generally, immediately after installation, or at a subsequent time, the WLAN is evaluated for its coverage and performance. As one step of this evaluation, the relative radio positions of the WAPs of the WLAN are determined. One technique for this determination is accomplished at step 930-948. As a first operation in this evaluation, a WAP receives a system evaluation direction from the air controller (step 930). In response to the system evaluation direction, the WAP listens for beacons of other WAPs (step 932). These beacons will typically be on particular channels at particular times. When the WAP hears a beacon, it controls its directional antenna in the direction of the beacon (step 934). Then, the WAP measures the maximum signal strength of the beacon (step 936). Steps 932, 934, and 936 will be repeated for each beacon. The air controller, in the system evaluation direction, may identify the beacon channels and beacon intervals to the WAPs. Alternately, the WAP will simply scan for beacons on each serviced channel, record information, and continue until directed to stop by the air controller. Finally, the WAP prepares a report regarding the beacon and provides the report to the air controller (step 938).

At step 940, the WAP receives a system beacon direction from the air controller (step 940). In response to the system beacon direction, the WAP selects a channel (step 942) and transmits a beacon on the selected channel (step 944). In one operation, the WAP transmits in a non-directional manner. However, in another operation, the WAP transmits with a previously determined directionality. With step 944 complete, the WAP optionally selects a new channel based upon the received direction or based upon another received direction (step 946) and transmits a beacon on the new selected channel (step 948). From steps 938 and 948 operation returns to step 902.

FIG. 10 is a logic diagram illustrating air controller operations according to the present invention. When the air controller is not performing operations of the present invention, it is either idle or performing other of its operations (step 1002). During a first operation of the present invention, the air controller receives a WAP operational report from a serviced WAP (step 1004). The air controller then stores the WAP operation report in its memory (step 1006). From step 1006 operation returns to step 1002.

In a second operation from step 1002, the air controller processes the received WAP operational reports to characterize system performance of the WLAN (step 1012). Based upon this system performance characterization, the WAP determines whether WAP directions are required (step 1014). If WAP directions are not required, operation proceeds from step 1014 to step 1002. However, if WAP directions are required, the air controller creates directions for at least some of the WAPs of the serviced WLAN (step 1016). Then, the air controller forwards the directions to respective WAPs (step 1018). Because the directions may only alter operation of one of the WAPs, at step 1018, the directions are forwarded to only targeted WAPs of the

plurality of WAPs of the WLAN. However, in other operations, the directions are forwarded to a number of respective WAPs that are requested to alter their operations. In still another operation, the directions are broadcast to all managed WAPs. From step 1018 operations returns to step 1002.

5   According to a further operation, the air controller may determine that it can no longer simply adjust operations of the WAPs but that WAP placement alterations are required (step 1020). In such case, the air controller identifies the WAP(s) requiring altered placement (step 1022). Such determination may be made by the air controller based upon its continued attempted adjustment of the WAP without producing sufficient WLAN system performance improvement.

10 In its operations, the air controller may also identify a direction in which to move a WAP with respect to other WAPs (step 1024). The air controller then sends a report to a WLAN manager that includes directions for WAP movement (step 1026). From step 1026 operation returns to step 1002.

    FIG. 11 is a logic diagram illustrating mobile terminal operations according to one

15 embodiment of the present invention. At step 1102 the wireless terminal is idle. From step 1102 the wireless terminal may initiate service within the WLAN (step 1104) or select another servicing WAP (step 1114). From step 1104, the wireless terminal listens to a plurality of beacons transmitted by a corresponding plurality of Wireless Access Points (WAPs) of the WLAN (step 1104). The wireless terminal then characterizes the plurality of beacons with

20 regard to signal quality (step 1106). Based upon the characterization, the wireless terminal selects a desired WAP of the plurality of WAPs (step 1108). The wireless terminal then associates with the desired WAP of the plurality of WAPs (step 1110). Finally, the wireless

terminal adjusts a gain vector of a servicing antenna of the wireless terminal so that it is substantially directed toward the desired WAP of the plurality of WAPs (step 1112).

From step 1114, the wireless terminal again listens to the plurality of beacons and again characterizes the plurality of beacons with regard to signal quality (step 1116). Based upon this characterization, the wireless terminal may select a different WAP of the plurality of WAPs (step 1120), disassociate with the desired WAP of the plurality of WAPs (step 1118), and associate with the different WAP of the plurality of WAPs (step 1122). The wireless terminal may then adjust the gain vector of the servicing antenna of the wireless terminal so that it is substantially directed toward the different WAP of the plurality of WAPs (step 1124).

At steps 1106 and 1116, in listening to the plurality of beacons, the wireless terminal may sweep the gain vector of the servicing antenna until a beacon is detected. When the beacon is detected the wireless terminal may then characterize the beacon. In this operation, the beacon is characterized when the gain vector of the servicing antenna is substantially directed toward the beacon.

Characterization of the beacon at steps 1106 and/or 1116 may take one or more of a number of characterization operations. In a first operation, characterizing the plurality of beacons with regard to signal quality includes measuring signal strengths of at least some of the plurality of beacons. In a second operation, characterizing the plurality of beacons with regard to signal quality includes measuring a signal to noise ratio corresponding to at least some of the plurality of beacons. In a third operation, characterizing the plurality of beacons with regard to signal quality includes receiving loading data carried by at least some of the plurality of beacons and processing received loading data to determine the desired WAP of the plurality of WAPs.

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Loading data represents the amount of traffic serviced by a WAP as reported in its beacon. It may be the case that a wireless terminal may select a WAP based upon not only the signal quality that is provided by the WAP but upon the service level that the WAP may provide to the wireless terminal.

5   In a fourth operation, characterizing the plurality of beacons with regard to signal quality includes receiving capability data carried by at least some of the plurality of beacons, wherein the capability data indicates whether a corresponding access point is capable of directional antenna servicing and processing received capability data to determine the desired WAP of the plurality of WAPs. In a fifth operation, characterizing the plurality of beacons with regard to signal

10   quality includes receiving capability data carried by at least some of the plurality of beacons, wherein the capability data indicates whether a corresponding access point is capable of transmit power control and processing received capability data to determine the desired WAP of the plurality of WAPs.

The invention disclosed herein is susceptible to various modifications and alternative

15   forms. Specific embodiments therefore have been shown by way of example in the drawings and detailed description. It should be understood, however, that the drawings and description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the invention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the present invention as defined by the claims.

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